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ARCTIC ACOUSTIC TOMOGRAPHY MIZEX 84(U) WOODS HOLE
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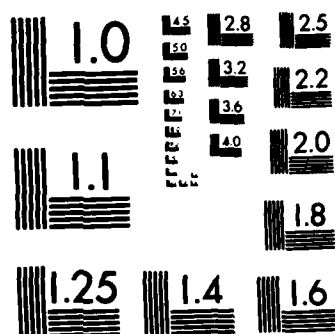
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ARCTIC ACOUSTIC TOMOGRAPHY
MIZEX 84

by

Robert C. Spindel, Principal Investigator

Woods Hole Oceanographic Institution

Woods Hole, Massachusetts 02543

April 1985

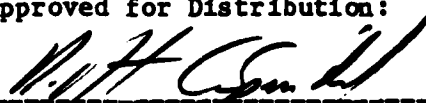
TECHNICAL REPORT

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Robert C. Spindel, Chairman
Department of Ocean Engineering

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Abstract

This is the final report of Contract N00014-84-C-0185 between the Woods Hole Oceanographic Institution and the Office of Naval Research for the contract period 1 January, 1984, to 28 February, 1985. This contract supported an experiment ~~that was~~ conducted in the Norwegian Sea during May and June of 1984 to assess the possibilities of using ocean acoustic tomography as a measuring tool in the Arctic. The object of the experiment was to identify and determine the temporal stability (coherence), and resolvability, of Arctic acoustic paths. Identification refers to the ability to match a pulse arrival with a particular ray path, primarily through computer modelling. Resolvable rays are those that arrive sufficiently far apart in time so as to be distinct and separable. In order to use tomography, rays must be identified, resolved and stable. Unlike the deep temperate ocean, where there are many wholly refracted paths, the upward refracting Arctic sound speed profile causes ray paths to reflect off the ice-covered surface of the permanent pack and the mixed ice-covered and ice-free surface of the marginal ice zones. The reflection process is time-varying and hence leads to resolvability, identification and stability questions that do not arise in the case of entirely refracted paths.

A 224 Hz acoustic source, was moored in an ice-free region, it transmitted phase coded, frequency stable signals to receivers fixed on the bottom and receivers drifting with the icepack at ranges of approximately 150 km. The received signals are to be analyzed with respect to identification, resolvability and stability issues.

This contract covered the costs associated with installation and retrieval of the source and preliminary data reduction from the drifting and fixed hydrophones. Detailed data analysis costs are to be covered elsewhere. Nevertheless, preliminary analysis indicates that the received signals, particularly those from paths that interact with the ice-free surface, appear to have sufficient stability for tomographic purposes.

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Experiment Summary

An autonomous, moored, acoustic transmitter was deployed on Leg 1 of the USNS Lynch cruise, in May, 1984, to assess the suitability of surface reflected acoustic paths in the Arctic and Marginal Ice Zones for tomographic application. The experiment was conducted as part of the international MIZEX 84 exercise which began in May and ended in August, 1984 (Figure 1).

The source transmitted a 224 Hz carrier, phase modulated by a binary, maximal-length, shift-register sequence, similar to the type of signal transmitted during several previous tomography experiments. Minor adjustments in signalling parameters were made to account for the Doppler shift due to the time-varying ocean surface. The object is to shift the side bands of the signal away from the approximately 0.1 Hz peak of the surface wave spectrum. Table I shows the modulation parameters for this and other tomography experiments.

The signal was received on hydrophones suspended through the ice by an MIT/WHOI scientific party aboard the MV Kvitbjorn, and by hydrophones resting on the bottom which were deployed by a party from NUSC aboard the HU Sverdrup.

The source was moored at a depth of 175 meters in 1207 (corrected) water at $78^{\circ}59'.3$ N, $6^{\circ}58'.6$ E (Figure 2). It began transmitting at 0000Z on Julian day 161 (9 June) and ceased at 0000Z on day 171. The transmission sequence consisted of two hours of continuous emissions starting at 0000Z each day. Following this there were 3 minute transmissions at the start of each hour beginning at 0300Z and lasting through 2300Z. The 224 Hz carrier was phase modulated by a 63 bit binary sequence (Table II). Each digit of the code, which consisted of 14 cycles of the 224 Hz carrier, was phase shifted

	1978 Pacific Test	1978 Path Stability Tests	1981 Density Tomography	1983 Velocity Tomography	1984 Gulf Stream Tomography	1984 Marginal Ice Zone Tomography
Carrier, f_0 (Hz)	220	220	224	400	400	224
Digits, N	63	63	127	511	511	63
Digit duration, d (s)	0.1	0.063	0.0625	0.01	0.01	0.0625
Sequence duration, $L = Nd$ (s)	6.3	4.00909	7.9375	5.11	5.11	3.9375
Repetitions, R	10	16	24	24	42	1820
Modulation angle, θ_0 (degrees)	45	45	75	87.5	87.5	85
Pulse compression gain (db)	18	18	21	27	27	18
Coherent averaging gain (db)	10	12	13.8	13.8	16.3	20(?)
Total signal pro- cessing gain (db)	28	30	34.6	40.8	43.8	38(?)
3 db bandwidth (Hz)	10	15.7	16	100	100	16
Spectral line spacing (Hz)	0.158	0.249	0.126	0.196	0.196	0.254
Arrival time error, σ_t (ms)	1.6	1.8	1.0	0.1	0.06	0.7(?)

TABLE I. Signal parameters for various tomography experiments.

0000	0100	0011	0001	0100	1111	0100	0111
0010	0101	1011	1011	0011	0101	0111	111

TABLE II. 63 digit code transmitted by the source. A '0' represents a carrier phase shift of + 82.82 degrees; a '1' represents a shift of - 82.82 degrees.

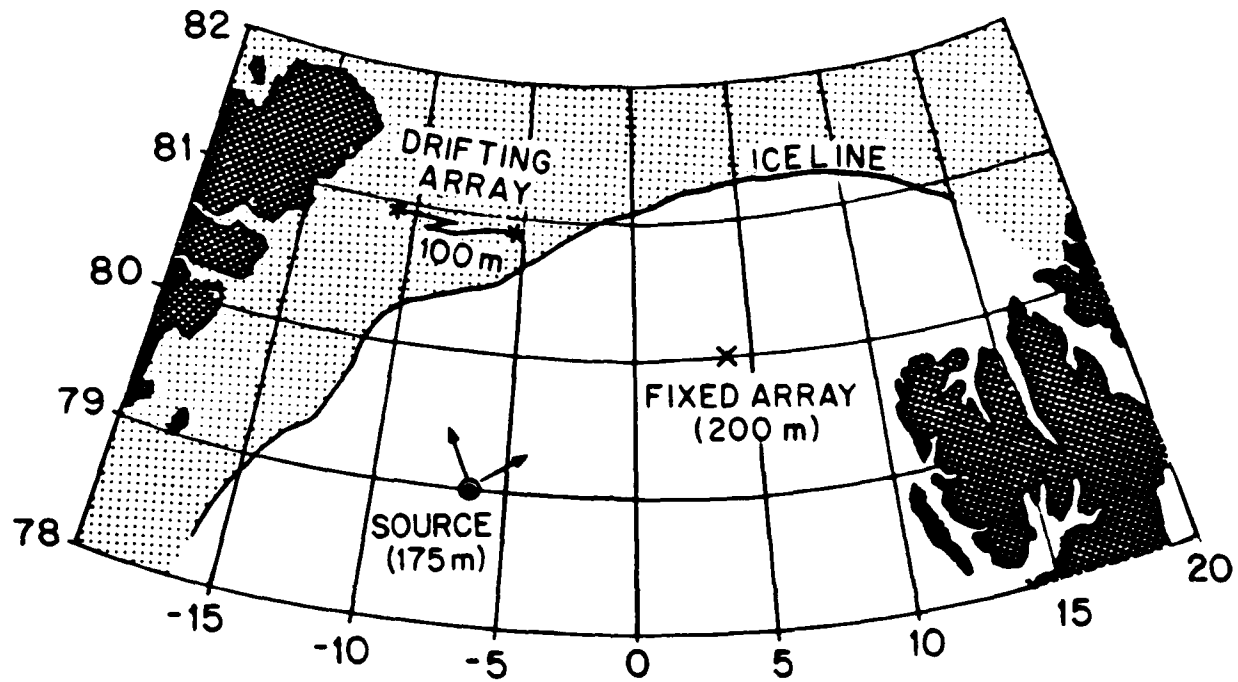


FIGURE 1

Location of 224 Hz acoustic source, and receiving hydrophones.
Numbers in parentheses indicate sensor depths.

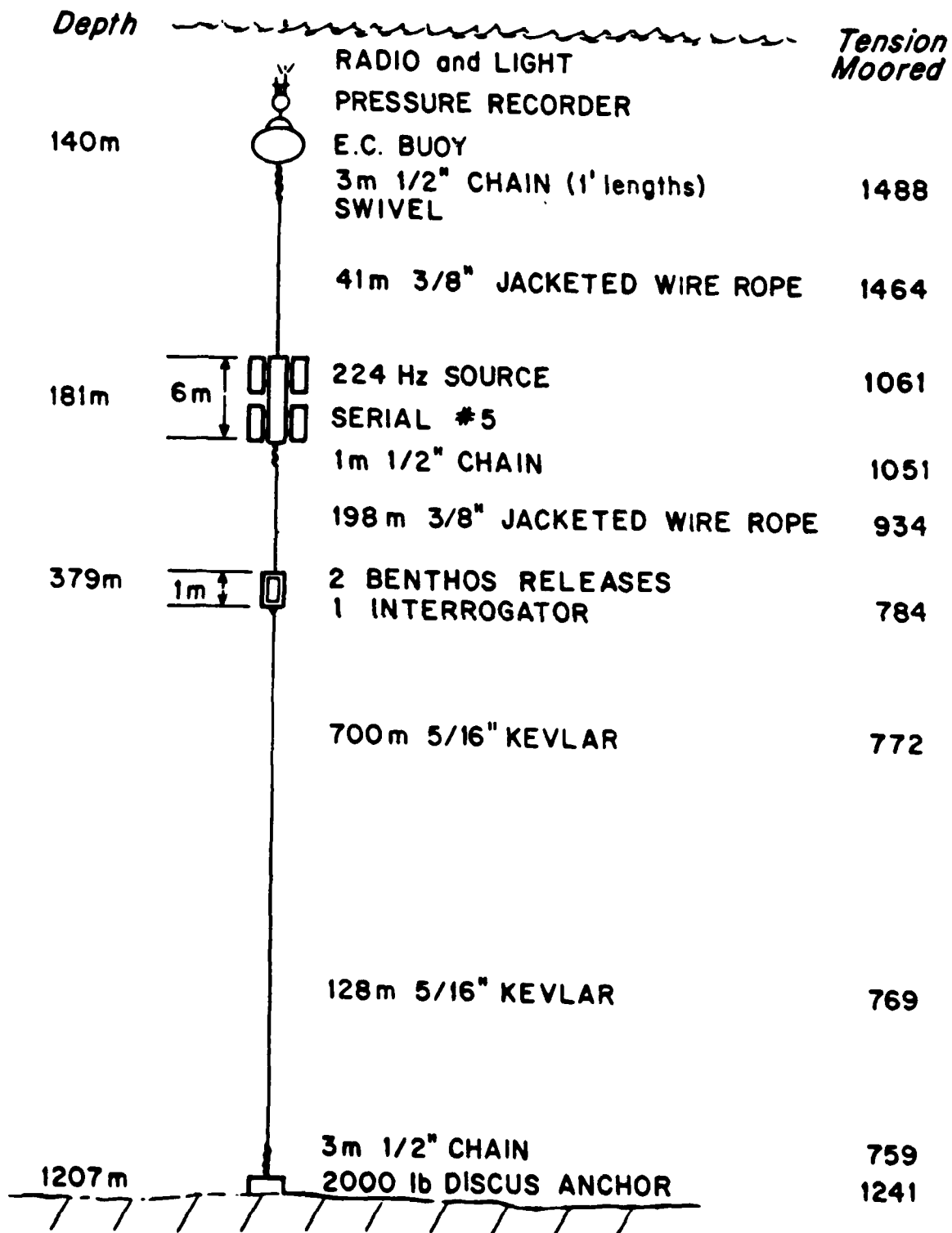


FIGURE 2

Source mooring configuration.

± 82.82 degrees depending on whether the digit was a zero or a one. This modulation angle results in a signal with smooth $(\sin x)/x$ spectral envelope and in maximum signal-to-noise ratio upon reception. The total transmission time for an entire 63 digit sequence was $63 \text{ digits} \times 14/224 \text{ seconds/digit} = 3.9375 \text{ seconds}$. The once daily two hour transmission consisted of a continuous repetition of this sequence; the hourly three minute transmissions consisted of 48 repetitions.

An infinite repetition of the signal has an autocorrelation function with a single peak at zero delay of width $14/224 = .063 \text{ s}$ and has no sidelobes. The correlation function is produced upon reception by circular correlation with a stored replica of the transmitted signal. The result of this processing is equivalent to having transmitted a signal pulse of $.063 \text{ s}$ width, but with 63 times the intensity. The net signal processing gain is therefore $10 \log (63) = 18 \text{ dB}$. Additional gain of $10 \log (N)$ is achieved by coherent averaging N repetitively transmitted sequences. Table I suggests a gain of 20 dB from this source ($N = 100$). Both of these processing techniques depend on temporally stable, phase coherent signals. A large part of this experiment was to determine the extent of such stability.

The mooring was equipped with a system to measure the position of the source as the mooring moved in response to tidal and other forcing currents (Figure 3). An acoustic interrogator transmitted 10.5 KHz pulses to transponders fixed to the ocean floor in an equilateral triangle about the base of the mooring. The transponders replied at unique frequencies in the 10 to 14 KHz band, and the round trip travel time of the process was recorded. These times were converted to slant ranges to determine the position of the interrogator (and therefore the source) to an accuracy of about 1-2 meters.

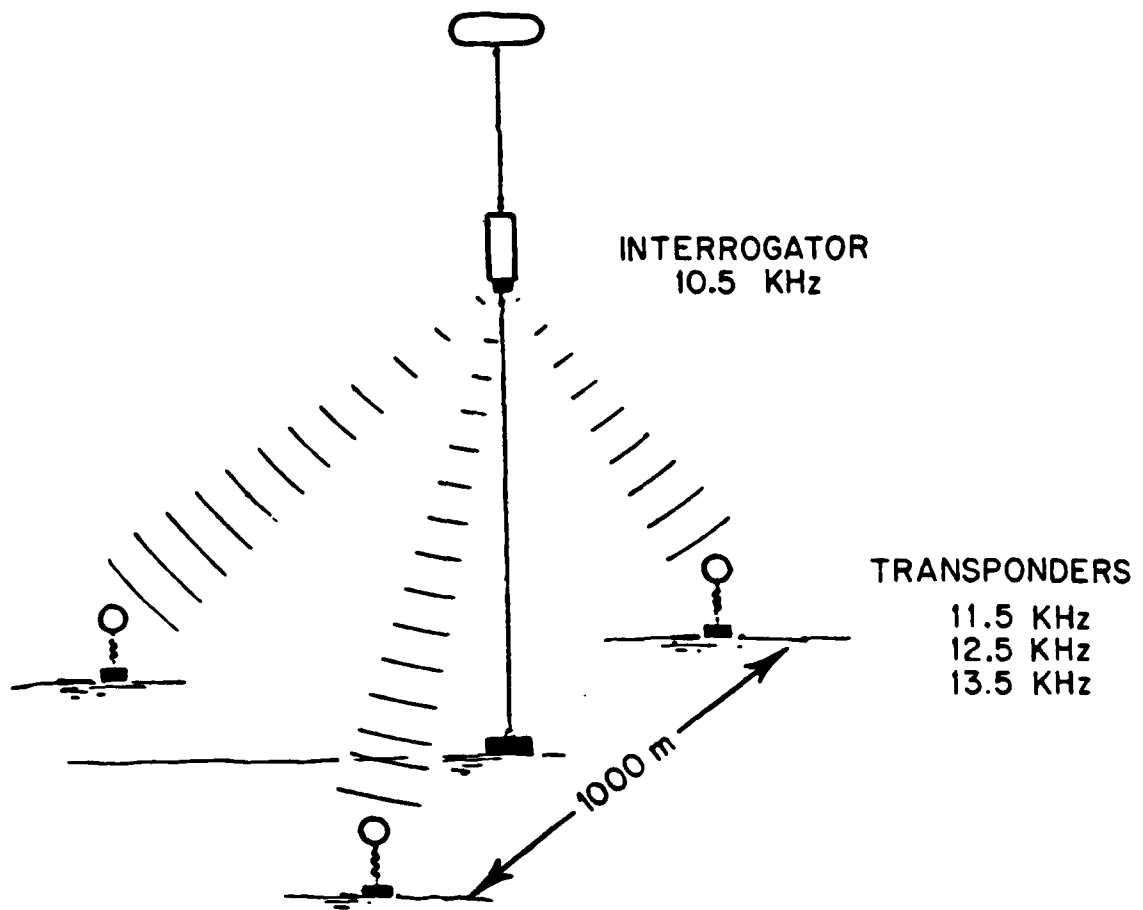


FIGURE 3

Mooring motion monitoring system. The interrogator measures and stores the round trip travel times to each of 3 transponders, thereby establishing three slant ranges and the position of the interrogator.

Results

The acoustic source was deployed successfully; it turned on automatically on June 9 (when listening hydrophones had been installed). Strong signals were received by both the ice-suspended hydrophones and the bottom hydrophones.

The signals received by the ice-suspended hydrophones were subjected to varying Doppler shifts due to the motion (drift) of the ice. The rate varied, but was in the range 1-2 cm/s (0.04kt) in the direction of the source. This motion results in a phase roll that ultimately limits coherent averaging gain. It also obscures the ultimate path stability; it is difficult to say whether phase instabilities are due to ice-drift motion or to fundamental oceanic processes such as surface or ice scatter, internal waves, instabilities in the water column, turbulence, etc.

However, some estimate of the stability can still be obtained from the drifting hydrophone data by normalizing the phase of the receptions with respect to the strongest arrival. This process removes the phase variations of this one path and allows examination of path-to-path stability. An example of a 46 sequence average (181 seconds) processed this way is shown in Figure 4.

Figure 5 is an example of the results obtained with the fixed hydrophone. Here coherent processing gains can be had for much longer averaging periods because there are no unknown phase instabilities due to sensor motion.

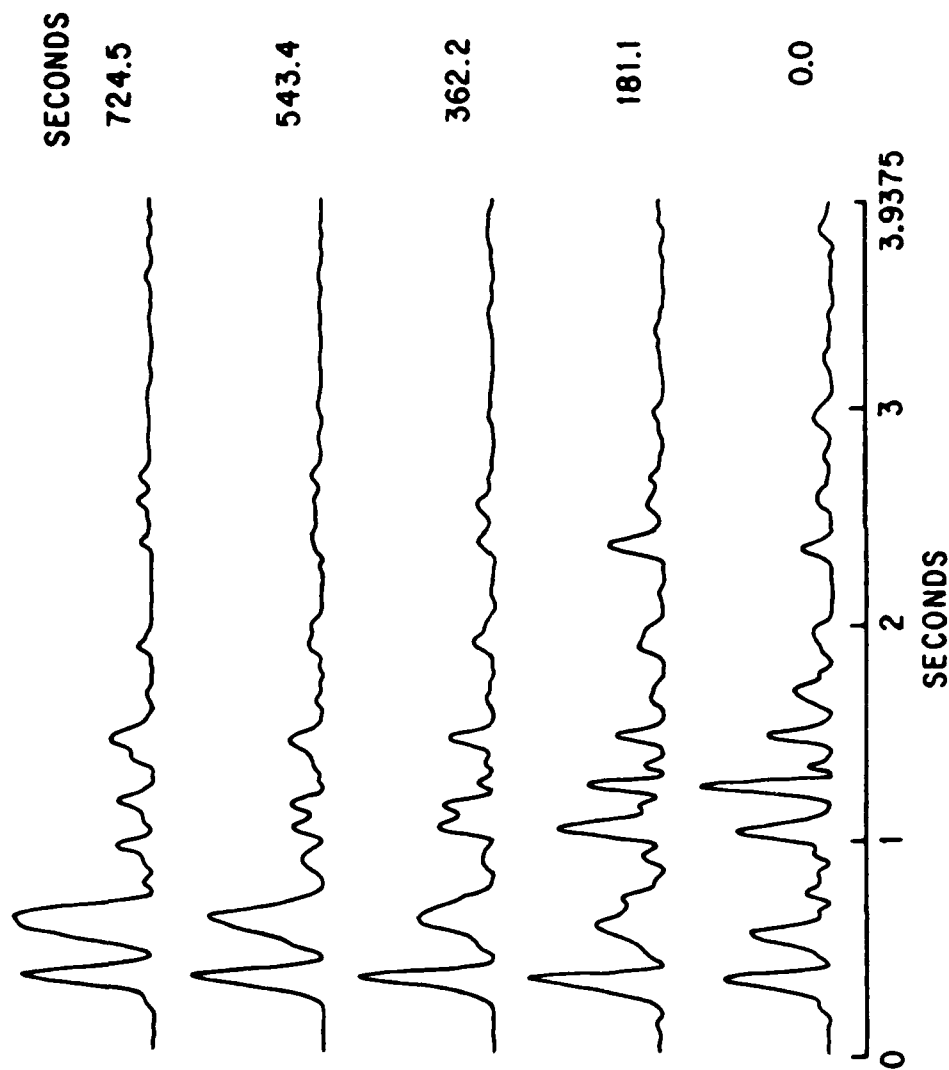


FIGURE 4

Drifting Hydrophone - Five consecutive 46 sequence averages. Each represents $46 \times 3.9375 = 181.125$ s. The five sequences span 15 minutes.

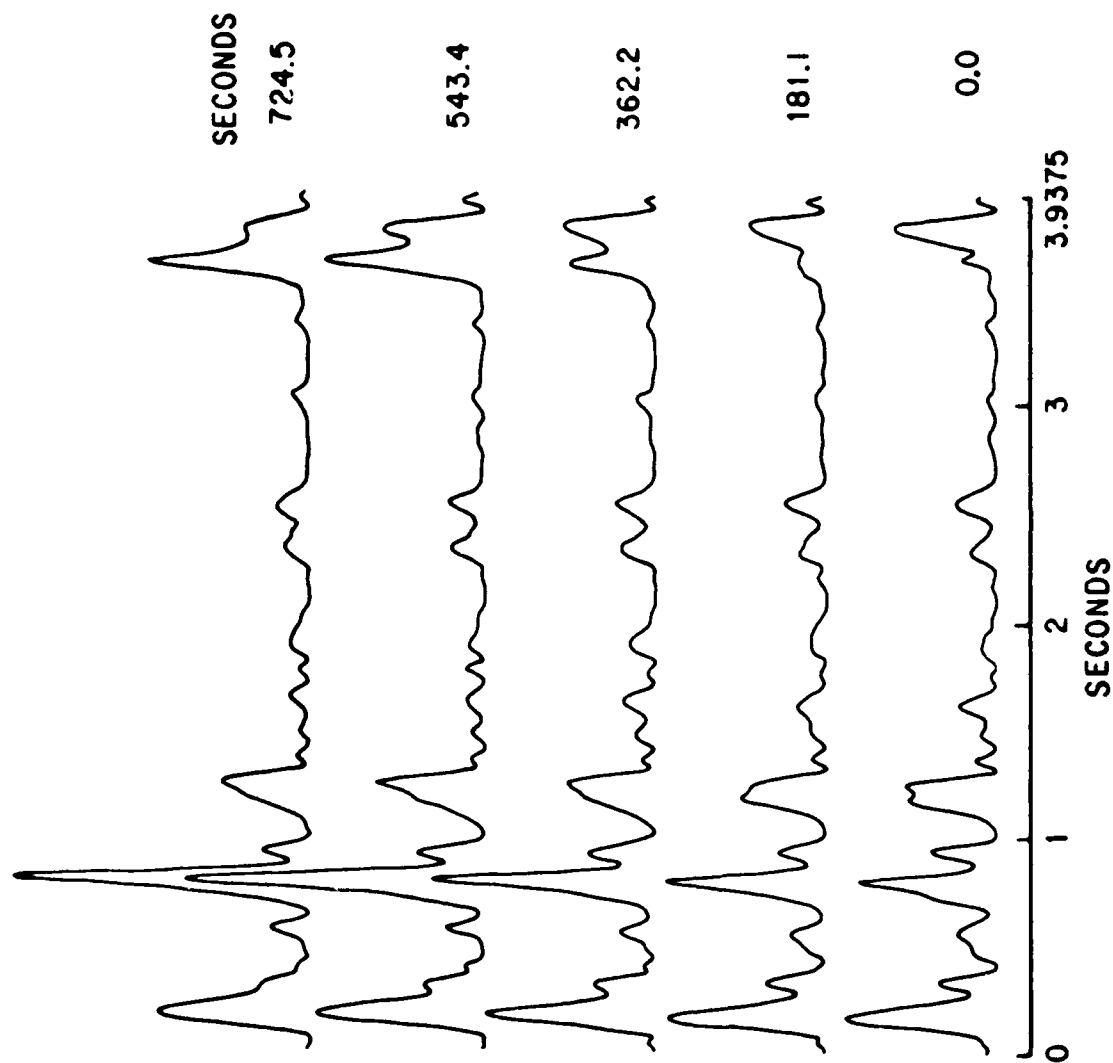


FIGURE 5

Bottom Fixed Hydrophone - Five consecutive 46 sequence averages. Each represents $46 \times 3.9375 = 181.125$ s. The five sequences span 15 minutes.

Conclusions

An experiment to test the feasibility of doing acoustic tomography in the upward refracting sound speed environment of the Arctic was performed during MIZEX 84. An acoustic source similar to the type used in previous tomography experiments was deployed in an ice-free region of the Fram Straits and signals were received on hydrophones suspended from the drifting ice pack and from hydrophones lying motionless on the ocean bottom.

The experiment suggests that tomography can be employed in the Arctic and Marginal Ice Zones in much the same way that it is being employed in more temperate seas. It suggests that purely upward refracted paths with reflections from the moving ice-pack, or with reception on hydrophones drifting with the ice, will be difficult to interpret, but that they still can (in theory) be useful. On the other hand, reflection from open water surfaces will not seriously degrade the tomography measurement.

Preliminary results have appeared in "Arctic tomography feasibility experiment in Mizex 84", R. Spindel, J. Lynch, M. Jones, J. Acoust. Soc. Amer., S56(A), 1985.

This report only covers the installation of the acoustic source and some very preliminary data analysis. Work is continuing under other ONR contractual arrangements.

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